ABSTRACT

In one aspect the invention provides a method for laser induced breakdown of a material with a pulsed laser beam where the material is characterized by a relationship of fluence breakdown threshold (F_{th}) versus laser beam pulse width (T) that exhibits an abrupt, rapid, and distinct change or at least a clearly detectable and distinct change in slope at a predetermined laser pulse width value. The method comprises generating a beam of laser pulses in which each pulse has a pulse width equal to or less than the predetermined laser pulse width value. The beam is focused to a point at or beneath the surface of a material where laser induced breakdown is desired.

The beam may be used in combination with a mask in the beam path. The beam or mask may be moved in the x, y, and Z directions to produce desired features. The technique can produce features smaller than the spot size and Rayleigh range due to enhanced damage threshold accuracy in the short pulse regime.

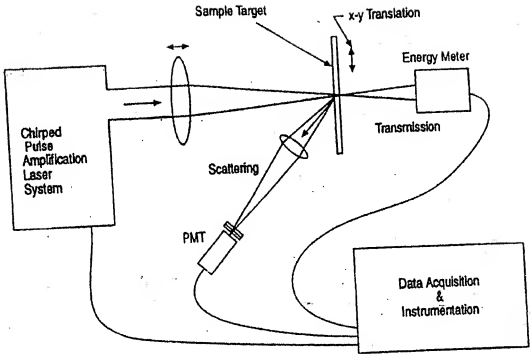


FIG. 1

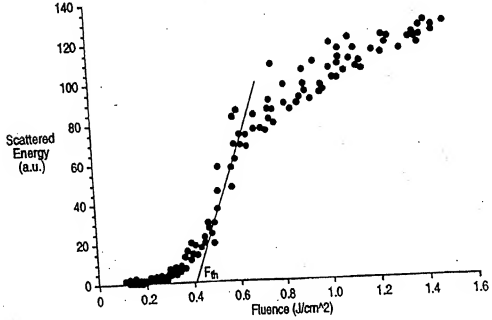


FIG. 2

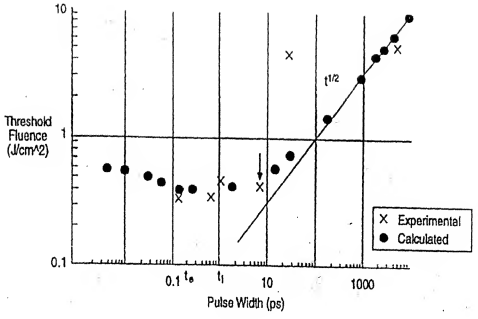


FIG. 3

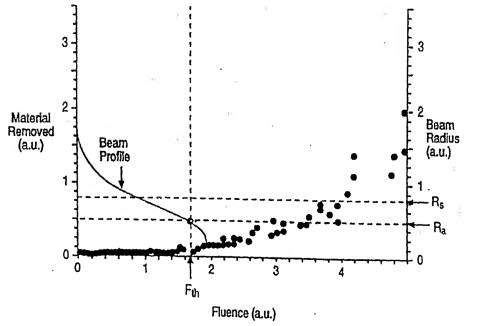


FIG. 4

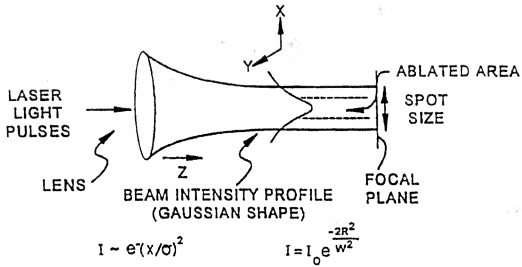
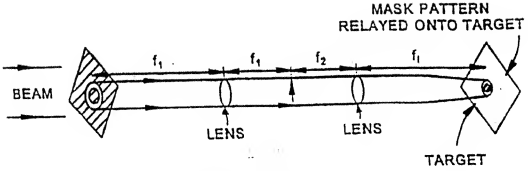


FIG.5

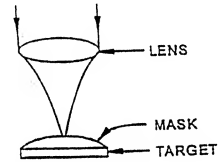
f_1 , f_2 - FOCAL LENGTH OF LENSES
$f_1 = mf_2$ WHERE m IS ARBITRARY



IMAGING SYSTEM

MASK - CROSS HATCHED AREAS
ARE OPAQUE TO LASER WAVELENGTH

FIG.6A



TARGET BEING
ABLATED WITH MASK

TARGET AFTER ABLATION IS ESSENTIALLY
IMAGE OF MASK.

FIG.6B

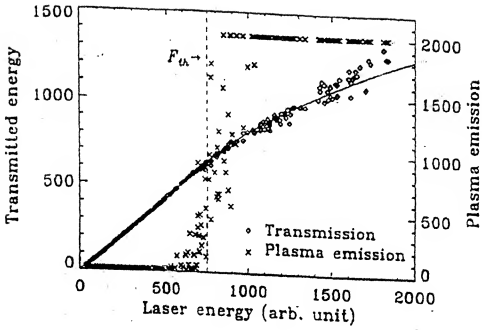


FIGURE 7

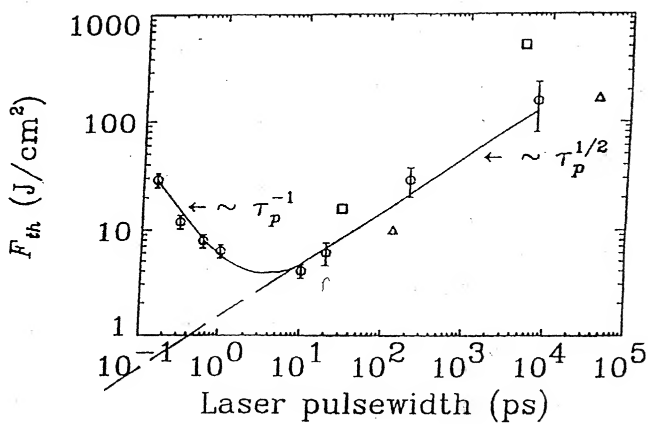

1000
100
10
1
10^{-1} 10^{0} 10^{1} 10^{2} 10^{3} 10^{4} 10^{5}
F_{th} (J/cm^2)
Laser pulsewidth (ps)
$\leftarrow \sim \tau_p^{-1}$
$\leftarrow \sim \tau_p^{1/2}$

FIGURE 8

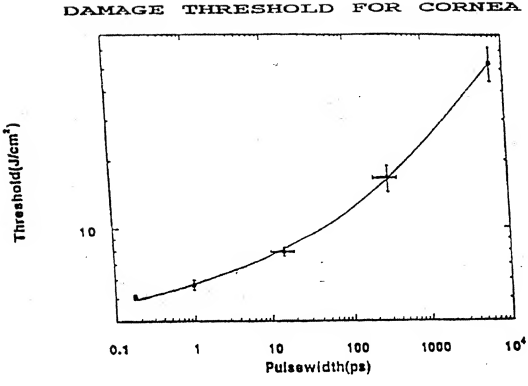


FIGURE 9

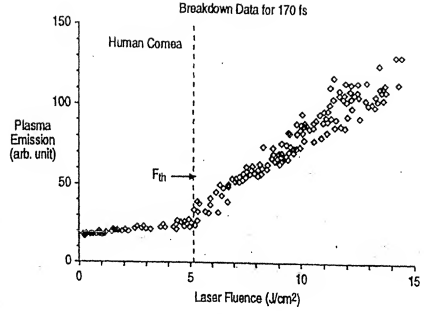


FIG.10

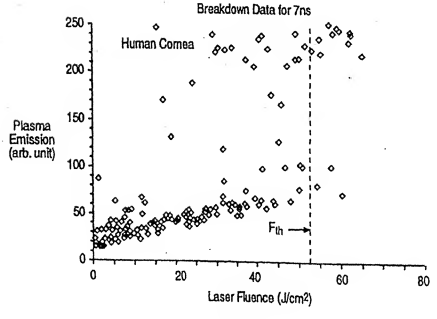


FIG.11

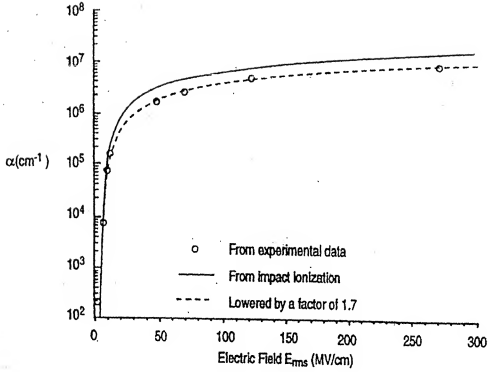


FIG.12

DAMAGE ALONG THE Z AXIS

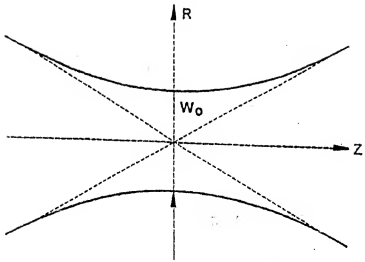


FIG.13A

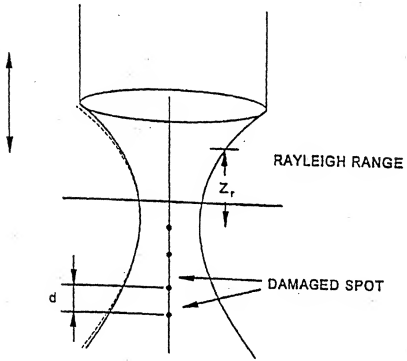


FIG.13B